IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of :

Yuya HASEGAWA et al. :

Serial No. 10/518,547 : Group Art Unit: 2834

Filed January 3, 2005 : Examiner: Burton S. Mullins

For: ACTUATOR

VERIFICATION OF ENGLISH TRANSLATION

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

I, Nobuyoshi MITANI , declare that I am conversant in both the Japanese and English languages and that the English translation as attached hereto is an accurate translation of Japanese Patent Application No. 2002-342761 filed on November 26, 2002.

Signed this 19 th day of May, 2006

Nobuyoshi Mitani

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PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: November 26, 2002

Application Number: Patent Application No. 2002-342761

Applicant(s): Matsushita Electric Works, Ltd.

Document name:	Application for patent
Docket No.:	02P02947
Date of Application:	November 26, 2002
Addressee:	Commissioner, Patent Office

International Patent Classification: H02K 33/00

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Payment of Fees:
Prepayment Book No.: 013103
Amount to be paid: ¥21,000

Attached Document:

Item:	Specification	1 copy
Item:	Drawing	1 copy
Item:	Abstract	1 copy

Registration No. of General Power: 0206419

Request for Proof Transmission: Yes

Document Name: Specification

TITLE OF THE INVENTION: ACTUATOR

CLAIMS:

1. An actuator comprising:

a stationary member which has a coil;

a casing which contains the stationary member;

a first movable member which has a shaft and is supported by the casing so as to be moved in an axial direction of the shaft and in a rotational direction having the shaft as its rotational axis;

a second movable member which is arranged in the axial direction with the first movable member so as to be moved in the axial direction separately from the first movable member; and

a spring member which is deflected among the casing, the first movable member and the second movable member in the axial direction;

wherein electric current is caused to flow through the coil so as to move the first movable member in the axial direction and in the rotational direction;

wherein the stationary member includes a first stationary member for imparting to the first movable member or the second movable member a force oriented in the axial direction and a second stationary member for imparting to the first movable member or the second movable member a force oriented in the rotational direction;

wherein the coil includes a first coil for exciting a magnetic path passing through the first stationary member and a second coil for exciting a magnetic path passing through the second stationary member.

2. The actuator as claimed in Claim 1, wherein the first and second stationary members impart to one of the first and second movable members the force oriented in the axial direction and the force oriented in the rotational direction, respectively.

3. The actuator as claimed in Claim 1, wherein the first stationary member imparts to one of the first and second movable members the force oriented in the axial direction and the second stationary member imparts to the other of the first and second movable members the force oriented in the rotational direction.

4. The actuator as claimed in Claim 2 or 3, wherein one of the first and second movable members, which undergoes the force from the stationary member, has a magnet having a magnetization direction substantially orthogonal to the axial direction and provided symmetrically with respect to the rotational axis;

wherein a pair of the first stationary members are provided symmetrically with respect to the rotational axis and a pair of the second stationary members are provided symmetrically with respect to the rotational axis;

wherein the first coil excites the pair of the first stationary members in an antiphase mode and the second coil excites the pair of the second stationary members in an antiphase mode.

5. The actuator as claimed in Claim 4, wherein one of the first and second movable members, which undergoes the force from the first stationary members, has two magnets having opposite magnetization directions, respectively and the first stationary member is formed by a substantially E-shaped magnetic part having three magnetic pole portions arranged in the axial direction.

6. The actuator as claimed in Claim 5, wherein one of the first and

second movable members, which undergoes the force from the second stationary members, has two magnets having opposite magnetization directions, respectively and the second stationary member is formed by a substantially C-shaped magnetic part having two magnetic pole portions arranged in the axial direction.

7. The actuator as claimed in Claim 5 or 6, wherein an end portion of each of the magnets of the one of the first and second movable members, which undergoes the force from the first stationary members, is operated so as to traverse each of two recesses of the first stationary member.

DETAILED DESCRIPTION OF THE INVENTION:

[0001]

[Technical Field of the Invention]

The present invention relates to an actuator which is capable of moving in two directions of an axial direction and a rotational direction.

[0002]

[Prior Art]

Many actuators are adapted to move in one direction of a linear direction or a rotational direction. When an actuator is moved in two directions of the linear direction and the rotational direction, a motion direction converting mechanism for converting a motion direction mechanically is employed. However, the motion direction converting mechanism produces noises when converting the motion direction. Meanwhile, if reciprocation is performed in the linear direction, vibrations are caused by inertia force.

[0003]

Japanese Patent Laid-Open Publication No. 2002-199689 discloses,

in a linear oscillator in which a first movable member (plunger) having a shaft is disposed inside a stationary member (yoke) provided in a casing so as to have a gap with the stationary member and a magnetic path is excited by a coil such that the first movable member is moved in an axial direction of the shaft, an arrangement which includes a second movable member (amplitude control weight) for canceling inertia force of the first movable member and spring members disposed between the casing and the first and second movable members, in which by making the gap nonuniform relative to axial displacement (stroke position) of the first movable member, the first movable member performs resonant reciprocations in an axial direction of the shaft, i.e., in a linear direction and motion in a rotational direction having the shaft as its rotational axis without using the motion direction converting mechanism and in which vibrations due to inertia force in the axial direction can be reduced.

[0004]

[Patent document 1]

Japanese Patent Laid-Open Publication No. 2002-199689

[0005]

[Problems to be solved by the Invention]

However, although the arrangement disclosed in Japanese Patent Laid-Open Publication No. 2002-199689 is useful in that the movable member can be moved in the two directions in response to axial displacement of the movable member in a simple construction, relation between motion of the movable member in the axial direction and the motion of the movable member in the rotational direction is fixed by shape of the gap, so that the motion of the movable member in the axial direction and the motion of the movable member in the rotational

direction cannot be controlled independently of each other and thus, degree of freedom of operational control of the movable member is not so high.

[0006]

With a view to eliminating the above mentioned drawbacks of prior art, the present invention has for its object to upgrade degree of freedom of operational control of an actuator which is capable of reducing vibrations due to inertia force in an axial direction and moving in two directions of the axial direction and a rotational direction without using a motion direction converting mechanism.

[0007]

[Means for solving the Problems]

An actuator of Claim 1 comprises: a stationary member which has a coil; a casing which contains the stationary member; a first movable member which has a shaft and is supported by the casing so as to be moved in an axial direction of the shaft and in a rotational direction having the shaft as its rotational axis; a second movable member which is arranged in the axial direction with the first movable member so as to be moved in the axial direction separately from the first movable member; and a spring member which is deflected among the casing, the first movable member and the second movable member in the axial direction; wherein electric current is caused to flow through the coil so as to move the first movable member in the axial direction and in the rotational direction; wherein the stationary member includes a first stationary member for imparting to the first movable member or the second movable member a force oriented in the axial direction and a second stationary member for imparting to the first movable member or the second movable member a force oriented in the rotational direction; wherein the coil includes a first coil for exciting a magnetic path passing

through the first stationary member and a second coil for exciting a magnetic path passing through the second stationary member.

[0008]

Therefore, since a spring resonant system is formed by the first movable member, the second movable member, the casing and the spring member provided among these members and deflectable in the axial direction, while resonant operation of the first movable member or the second movable member is performed in the axial direction by imparting to the first movable member or the second movable member the force oriented in the axial direction upon excitation of the magnetic path passing through the first stationary member by the first coil and motion of the first movable member or the second movable member is performed in the rotational direction by imparting to the first movable member or the second movable member the force oriented in the rotational direction upon excitation of the magnetic path passing through the second stationary member by the second coil, the first movable member can be controlled independently in the axial direction and in the rotational direction.

Meanwhile, since the resonant operation of the first and second movable members can be, respectively, performed oppositely in the axial direction, vibrations caused by inertia force in the axial direction can be reduced.

As a result, since vibrations caused by inertia force can be reduced, it is possible to upgrade degree of freedom of operational control of the actuator which is capable of moving in two directions of the axial direction and the rotational direction.

[0009]

In Claim 2, the first and second stationary members impart to one of

the first and second movable members the force oriented in the axial direction and the force oriented in the rotational direction, respectively in the actuator of Claim 1.

[0010]

Therefore, since the other of the first and second movable members does not undergo the force from the stationary member, design of the spring resonant system is facilitated.

[0011]

In Claim 3, the first stationary member imparts to one of the first and second movable members the force oriented in the axial direction and the second stationary member imparts to the other of the first and second movable members the force oriented in the rotational direction in the actuator of Claim 1.

[0012]

Therefore, since the magnetic path for generating the force oriented in the axial direction and the magnetic path for generating the force oriented in the rotational direction are separated from each other, design of a magnetic circuit can be facilitated.

[0013]

In Claim 4, one of the first and second movable members, which undergoes the force from the stationary member, has a magnet having a magnetization direction substantially orthogonal to the axial direction and provided symmetrically with respect to the rotational axis, a pair of the first stationary members are provided symmetrically with respect to the rotational axis and a pair of the second stationary members are provided symmetrically with respect to the rotational axis and the first coil excites the pair of the first stationary members in an antiphase mode and the second coil excites the pair of the second stationary

members in an antiphase mode in the actuator of Claim 2 or 3.

[0014]

Therefore, since the first and second stationary members imparts, by using opposite magnetic poles of the magnet, to the one of the first and second movable members the force oriented in the axial direction and the force oriented in the rotational direction, the spring resonant system can be moved with great force.

[0015]

In Claim 5, one of the first and second movable members, which undergoes the force from the first stationary members, has two magnets having opposite magnetization directions, respectively and the first stationary member is formed by a substantially E-shaped magnetic part having three magnetic pole portions arranged in the axial direction in the actuator of Claim 4.

[0016]

Therefore, since the two magnets of the one of the first and second movable members are positioned so as to confront the first stationary members such that magnetic pole portions of the magnets are disposed at positions suitable for producing the force oriented in the axial direction, leakage flux is lessened and the spring resonant system can be efficiently moved in the axial direction with great force.

[0017]

In Claim 6, one of the first and second movable members, which undergoes the force from the second stationary members, has two magnets having opposite magnetization directions, respectively and the second stationary member is formed by a substantially C-shaped magnetic part having two magnetic pole portions arranged in the axial direction in the actuator of Claim 5.

[0018]

Therefore, since the two magnets of the one of the first and second movable members are positioned so as to confront the two magnetic pole portions of the second stationary member such that the magnetic pole portions of the second stationary member are disposed at positions suitable for producing the force oriented in the rotational direction, leakage flux is lessened and the first movable member can be efficiently moved in the rotational direction with great force.

[0019]

In Claim 7, an end portion of each of the magnets of the one of the first and second movable members, which undergoes the force from the first stationary members, is operated so as to traverse each of two recesses of the first stationary member in the actuator of Claim 5 or 6.

[0020]

Therefore, since an area for confronting magnetic pole portions of the magnets with the magnetic pole portions of the first stationary member can be increased, the spring resonant system can be moved in the axial direction with great force.

[0021]

[Embodiments of the Invention]

(First embodiment)

Hereinafter, a first embodiment of the present invention directed to Claims 1, 2 and 4 to 6 is described with reference to Figs. 1 to 9. The first embodiment is mainly formed by a casing 1, a first stationary member 2, a first coil 3, a second stationary member 4, a second coil 5, a first movable member 6, a

second movable member 7 and a spring member 8 as its main constituent elements.

[0022]

The casing 1 is formed by a housing portion 1a and a bearing portion 1b. The housing portion 1a is formed by metallic magnetic material into a cylindrical shape having a closed bottom, while the bearing portion 1b is provided at a central portion of each of opposite end faces of the housing portion 1a. The casing 1 accommodates the first stationary member 2, the first coil 3, the second stationary member 4, the second coil 5, the first movable member 6, the second movable member 7 and the spring member 8. The bearing portion 1b is formed into a sectional shape of a concentric hollow column so as to act as a bearing in which metal balls each having a smoothly worked surface are filled into the hollow. The bearing portion 1b is provided at each of the opposite end faces of the housing portion 1a such that a central axis of the housing portion 1a coincides with that of the bearing portion 1b. These bearing portions 1b can support a cylindrical shaft by the metal balls so as to move the shaft in its axial direction (hereinafter, referred to as an "axial direction") and in a rotational direction (hereinafter, referred to as a "rotational direction") having the axial direction as its central axis (hereinafter, referred to as a "rotational axis").

[0023]

The first stationary member 2 is formed by magnetic material into an E-shaped column in section and has three E-shaped magnetic pole portions arranged in the axial direction. A pair of the first stationary members 2 are mounted and accommodated in a hollow of the housing portion 1a of the casing 1 symmetrically with respect to the rotational axis. The three E-shaped magnetic

pole portions are formed symmetrically and have an identical width and an identical length. The first coil 3 is wound around the central magnetic pole portion and different magnetic poles are produced at the central magnetic pole portion and the opposite magnetic pole portions by causing electric current to flow through the first coil 3. For example, if an S-pole is produced at the central magnetic pole portion, an N-pole is produced at the opposite magnetic pole portions. Since these magnetic pole portions are disposed so as to confront the first movable member 6, an efficient magnetic circuit in which leakage flux is small is formed. The first stationary members 2 are mainly used for applying to the first movable member 6 a force oriented in the axial direction.

[0024]

The first coil 3 is wound around the central magnetic pole portion of the first stationary member 2 via a resinous coil bobbin (not shown). The first coil 3 is adapted to excite a magnetic path passing through the first stationary member 2, a gap and the first movable member 6. By causing electric current to flow through the first coil 3, different magnetic poles are produced at the central magnetic pole portion and the opposite magnetic pole portions. Meanwhile, the first coil 3 provided in one of the two stationary members 2 and the first coil 3 provided in the other first stationary member 2 are connected to each other so as to perform excitation in an antiphase mode. For example, when the central magnetic pole portion of the one first stationary member 2 is excited to an S-pole, the central magnetic pole portion of the other first stationary member 2 is excited to an N-pole upon connection of the two first coils 3.

[0025]

The second stationary member 4 is formed by magnetic material

into a C-shaped column in section and has two C-shaped magnetic pole portions arranged in the axial direction. A pair of the second stationary members 4 are mounted and accommodated in the hollow of the housing portion 1a of the casing 1 symmetrically with respect to the rotational axis. A plane containing the first stationary members 2 and a plane containing the second stationary members 4 intersect with each other orthogonally. Hence, since an interval between the first stationary member 2 and the second stationary member 4 becomes large, a space for providing the first coil 3 and the second coil 5 can be made large. The two C-shaped magnetic pole portions of the second stationary member 4 are formed symmetrically and have an identical width and an identical length. The two second coils 5 are, respectively, wound around the opposite magnetic pole portions dividedly and different magnetic poles are, respectively, produced at the opposite magnetic pole portions by causing electric current to flow through the two second coils 5. For example, if an S-pole is produced at one of the two magnetic pole portions, an N-pole is produced at the other magnetic pole portion. Since the opposite magnetic pole portions are disposed so as to confront the first movable member 6, an efficient magnetic circuit in which leakage flux is small is formed. The second stationary members 4 are mainly used for applying to the first movable member 6 a force oriented in the rotational direction.

[0026]

The two second coils 5 are, respectively, wound around the opposite magnetic pole portions of the second stationary member 4 dividedly by way of a resinous coil bobbin (not shown). The second coil 5 is adapted to excite a magnetic path passing through the second stationary member 4, a gap and the movable member 6. By causing electric current to pass through the second coils

5, different magnetic poles are, respectively, produced at the opposite magnetic pole portions of the second stationary member 4. Meanwhile, one of the second coils 5 provided in one of the two second stationary member 4 and a corresponding one of the second coils 5 provided in the other second stationary member 4 are connected to each other so as to perform excitation in an antiphase mode. For example, when one of the opposite magnetic pole portions of one second stationary member 4 is excited to an S-pole, a corresponding one of the opposite magnetic pole portions of the other second stationary member 4 is excited to an N-pole.

[0027]

The movable member 6 is formed by a shaft 6a and a driving force generator 6b. The shaft 6a is formed by a metallic cylinder and is supported by the two bearing portions 1b so as to be moved in the axial direction and in the rotational direction. The driving force generator 6b is formed by two cylindrical magnets 6ba and 6bb magnetized radially such that a magnetization direction oriented towards an N-pole from an S-pole in the magnet 6ba is opposite to that of the magnet 6bb. The magnets 6ba and 6bb are mounted on the shaft 6a such that a central axis of the magnets 6ba and 6bb coincides with that of the shaft 6a. Thus, the magnets 6ba and 6bb are provided symmetrically with respect to the rotational axis such that the magnetization directions of the magnets 6ba and 6bb intersect with the axial direction orthogonally. Therefore, since masses of the magnets 6ba and 6bb are distributed symmetrically with respect to the rotational axis, inertia force based on motion of the first movable member 6 in the rotational direction is cancelled and thus, vibrations to be transmitted to the casing 1 can be reduced. Meanwhile, since the first stationary members 2 and the second

stationary members 4 apply to the first movable member 6 the force oriented in the axial direction and the force oriented in the rotational direction by using the magnetic poles disposed at opposite sides of the magnets 6ba and 6bb of the first movable member 6, the first movable member 6 can be moved with great force. Each of the magnets 6ba and 6bb has a thickness equal to a width of each of two recesses of the E-shaped first stationary member 2. The magnets 6ba and 6bb are provided at such an interval on the shaft 6a that side faces of the magnets 6ba and 6bb confront the two recesses of the first stationary member 2, respectively. At this time, the magnets 6ba and 6bb confront the magnetic pole portions of the second stationary member 4, respectively. A diameter of the magnets 6ba and 6bb is determined such that a gap is defined between the driving force generator 6b and the first stationary member 2 and between the driving force generator 6b and the second stationary member 4.

[0028]

The second movable member 7 is formed by copper into a cylindrical shape having a diameter smaller than an inside diameter of the housing portion 1a and is provided with a circular through-hole having a diameter larger than that of the shaft 1a is provided at a central axis of the second movable member 7. The second movable member 7 is accommodated in the housing portion 1a and is disposed between the first movable member 6 and the casing 1 so as to be arranged in the axial direction such that the shaft 6a is inserted through the through-hole. The second movable member 7 is supported between the first movable member 6 and the casing 1 by using the spring member 8 to be described below so as to be moved in the axial direction separately from the first movable member 6. A mass of the second movable member 7 is so set as to be

substantially equal to that of first movable member 6.

[0029]

The spring member 8 is constituted by springs of a first spring 8a, a second spring 8b and a third spring 8c. A coiled spring deflectable in the axial direction is used as the spring member 8. The first spring 8a is provided between the casing 1 and the first movable member 6, the second spring 8b is provided between the first movable member 6 and the second movable member 7 and the third spring 8c is provided between the second movable member 7 and the casing 1. Opposite ends of each of the first to third springs 8a to 8c are attached to a location for providing the first to third springs 8a to 8c such that the spring member 8 acts as a spring also in the rotational direction

[0030]

By causing electric current to pass through the first coil 3 in the above described arrangement, magnetic poles shown in, for example, Fig. 2 are produced in the magnetic pole portions of the first stationary member 2. Then, the magnet 6ba undergoes an attraction force from the uppermost magnetic pole portion of the first stationary member 2 and a repulsion force from the central magnetic pole portion of the first stationary member 2. On the other hand, the magnet 6bb undergoes an attraction force from the central magnetic pole portion of the first stationary member 2 and a repulsion force from the lowermost magnetic pole portion of the first stationary member 2. Therefore, the first movable member 6 undergoes from the first stationary member 2 a force oriented in the axial direction, i.e., in the upward direction in Fig. 2. If electric current is caused to flow through the first coil 3 in a direction opposite to that of the above, polarities of magnetic poles produced in the magnetic pole portions become

opposite to those of the above, so that the first movable member 6 undergoes a force oriented in the opposite axial direction.

[0031]

Meanwhile, by causing electric current to pass through the second coil 5, magnetic poles shown in, for example, Fig. 4 are produced in the magnetic pole portions of the second stationary member 4. Thus, since the magnet 6ba undergoes a force mainly from the second stationary member 4, the magnet 6ba undergoes a force oriented in the clockwise rotational direction. Meanwhile, since the magnet 6bb also undergoes a force mainly from the second stationary member 4, the magnet 6bb undergoes a force oriented in the clockwise rotational direction. Therefore, the first movable member 6 undergoes from the second stationary member 4 the force oriented in the rotational direction, i.e., in the clockwise rotational direction in Fig. 4. Meanwhile, if electric current is caused to flow through the second coil 5 in a direction opposite to that of the above, polarities of magnetic poles produced in the magnetic pole portions of the second stationary member 4 become opposite to those of the above, so that the first movable member 6 undergoes a force oriented in the opposite rotational direction.

[0032]

Therefore, since the axial direction and the rotational direction of the first movable member 6 can be controlled independently of each other in this actuator, the actuator has thrust characteristics relative to axial displacement and torque characteristics relative to rotational angle in the rotational direction as shown in Fig. 5. Namely, when electric current does not flow through the first coil 3, electric current flows through the first coil 3 in a plus direction and electric current flows through the first coil 3 in a minus direction, thrust characteristics

shown by curves FZ1, FP1 and FM1, respectively are obtained. Meanwhile, when electric current does not flow through the second coil 5, electric current flows through the second coil 5 in a plus direction and electric current flows through the second coil 5 in a minus direction, torque characteristics shown by curves TZ1, TP1 and TM1, respectively are obtained. Here, a positional relation in which the first stationary member 2 and the first movable member 6 are disposed as shown in Fig. 2 is employed as a reference position of the thrust characteristics. Meanwhile, a positional relation in which the first stationary members 2, the second stationary members 4 and the first movable member 6 are disposed as shown in Fig. 4 is employed as a reference position of the torque characteristics. Therefore, if an AC voltage is applied to the first coil 3 and the second coil 5, electric current flows through the first coil 3 and the second coil 5 in the plus direction and the minus direction, respectively, so that the first movable member 6 is reciprocated in two directions of the axial direction and the rotational direction.

[0033]

Meanwhile, the casing 1, the first movable member 6, the second movable member 7 and the spring member 8 constitute a spring resonant system which performs resonant motion in the axial direction at a resonant frequency determined by their respective masses and respective spring constants of the spring member 8. This spring resonant system has two resonant frequencies when the spring resonant system can be approximated to a state in which the casing 1 is fixed. At one of the resonant frequencies (hereinafter, a "primary mode resonant frequency"), the first movable member 6 and the second movable member 7 are moved in an in-phase state. At the other resonant frequency

(hereinafter, a "secondary mode resonant frequency"), the first movable member 6 and the second movable member 7 are moved in an antiphase state. Therefore, if an AC voltage having a frequency close to the secondary mode resonant frequency is applied to the first coil 3, the first movable member 6 and the second movable member 7 perform resonant motion in the antiphase state. Thus, by the resonant motion, a large amplitude of the first movable member 6 can be obtained efficiently. Since the masses of the first movable member 6 and the second movable member 7 are set substantially equally, their inertia forces cancel each other, so that it is possible to reduce vibrations due to the axial inertia force applied to the casing 1.

[0034]

On the other hand, since the spring member 8 is the coiled spring, the spring member 8 functions as a spring in the rotational direction by fixing the opposite ends of the spring member 8. Hence, the casing 1, the first movable member 6, the second movable member 7 and the spring member 8 constitute a spring resonant system which performs resonant motion in the rotational direction at a resonant frequency determined by their respective moments of inertia and respective spring constants of the spring member 8 in the rotational direction. Therefore, if an AC voltage having a frequency close to the resonant frequency is applied to the second coil 5, a large amplitude in the rotational direction also can be obtained efficiently by the resonant motion.

[0035]

In the above, the frequency of the AC voltage is set close to the resonant frequency in order to perform the resonant motion because the resonant frequency is influenced by an electric circuit, etc. so as to deviate from a resonant

frequency determined by only a motion system.

[0036]

Meanwhile, if the second stationary member 4 is formed into an E-shaped configuration as shown in Fig. 6 in the same manner as the first stationary member 2, positional relation between the magnet 6ba and an uppermost magnetic pole portion of the second stationary member 4 in Fig. 7 generates a force for performing clockwise rotation of the magnet 6ba, while positional relation between the magnet 6bb and a lowermost magnetic pole portion of the second stationary member 4 in Fig. 7 generates a force for performing counterclockwise rotation of the magnet 6bb. Namely, the force for performing clockwise rotation of the magnet 6ba and the force performing counterclockwise rotation of the magnet 6bb block each other. Since magnetic pole faces of the magnets 6ba and 6bb do not confront those of the second stationary member 4, a force applied to the first movable member 6 is reduced. Therefore, by employing the C-shaped second stationary member 4, a force applied to the movable member 6 in the rotational direction can be made larger than that of the E-shaped second stationary member 4.

[0037]

Then, operation of the first embodiment is described. It is supposed here that the first movable member 6 is disposed at the above mentioned reference positions in the axial direction and the rotational direction and electric current is not flowing through the first coil 3 and the second coil 5. At this time, since the first movable member 6 is in a balanced state shown in Fig. 5, the first movable member 6 is at a standstill without undergoing any force both in the axial direction and in the rotational direction.

[0038]

If AC voltages of rectangular waves of the secondary mode resonant frequency represented by curves VS and VR1 are, respectively, applied to the first coil 3 and the second coil 5 as shown in Fig. 8, AC flows through the first coil 3 and the second coil 5. Thus, the first coil 3 excites the magnetic path passing through the first stationary member 2, while the second coil 5 excites the magnetic path passing through the second stationary member 4. Hence, the first movable member 6 undergoes the force oriented in the axial direction and the force oriented in the rotational direction as shown in Fig. 5. Phase of AC flowing through the first coil 3 and the second coil 5 changes according to motion of the first movable member 6, the number of the coil, etc. but the first movable member 6 is moved through the resonant motion in the axial direction as shown by, for example, a curve DS of Fig. 8 by AC flowing through the first coil 3. At this time, the second movable member 7 is operated in an antiphase state relative to the curve DS. On the other hand, in the phase shown in, for example, Fig. 8, the second coil 5 performs counterclockwise rotation of the first movable member 6 in an interval RL and clockwise rotation of the movable member 6 in an interval RR. Therefore, the first movable member 6 performs the resonant motion so as to reciprocate in the rotational direction at a period identical with that of the axial direction while reciprocating in the axial direction.

[0039]

Meanwhile, axial motion and rotational motion of the movable member 6 can be controlled independently of each other. Thus, if a frequency of an AC voltage applied to the second coil 3 is set twice that of an AC voltage applied to the first coil 3 as shown by a curve VR2 in Fig. 9, the movable member

6 can be reciprocated twice in the rotational direction while reciprocating in the axial direction.

[0040]

In the first embodiment, the spring resonant system is constituted by the first movable member 6, the second movable member 7, the casing 1 and the spring member 8 deflectable among them in the axial direction and the force oriented in the axial direction is applied to the movable member 6 when the magnetic path flowing through the first stationary member 2 is excited by the first coil 3, while the force oriented in the rotational direction is applied to the first movable member 6 when the magnetic path flowing through the second stationary member 4 is excited by the second coil 5. Thus, axial motion and rotational motion of the first movable member 6 can be controlled independently of each other. Meanwhile, since the first movable member 6 and the second movable member 7 can be moved in the opposite axial directions, respectively in the resonant motion in the axial direction, it is possible to lessen vibrations due to the inertia force in the axial direction. As a result, the vibrations due to the inertia force in the axial direction can be lessened and it is possible to upgrade degree of freedom of operational control of the actuator in which the movable member 6 can be moved in two directions of the axial direction and the rotational direction without using a motion direction converting mechanism.

[0041]

Meanwhile, since the first and second stationary members 2 and 4 imparts to the first movable member 6 the force oriented in the axial direction and the force oriented in the rotational direction, respectively and the second movable member 7 does not undergo any force from the first and second stationary

members 2 and 4, design of the spring resonant system is facilitated.

[0042]

Since masses of the magnets 6ba and 6bb of the first movable member 6 are distributed symmetrically with respect to the rotational axis, inertia force based on rotational motion of the first movable member 6 is cancelled and thus, vibrations to be transmitted to the casing 1 can be reduced. Meanwhile, since the first stationary members 2 and the second stationary members 4 apply to the first movable member 6 the force oriented in the axial direction and the force oriented in the rotational direction, respectively by using the magnetic poles disposed at opposite sides of the magnets 6ba and 6bb of the first movable member 6, so that the first movable member 6 can be moved with great force.

[0043]

Furthermore, if the first stationary member 2 is formed into the E-shaped configuration and the second stationary member 4 is formed into the C-shaped configuration such that the first stationary member 2 and the second stationary member 4 are disposed so as to intersect with each other orthogonally, an interval between the first stationary member 2 and the second stationary member 4 becomes large, so that a space for providing the first coil 3 and a space for providing the second coil 5 can be increased. Meanwhile, when the magnets 6ba and 6bb of the first movable member 6 are positioned so as to confront the first stationary member 2, the magnetic pole portions of the first stationary member 2 are disposed at positions suitable for producing the force in the axial direction, so that leakage flux is lessened and the first movable member 6 can be efficiently moved in the axial direction with great force. Meanwhile, when the magnets 6ba and 6bb are positioned so as to confront the two magnetic pole

portions of the second stationary member 4, the magnetic pole portions of the second stationary member 4 are disposed at positions suitable for producing the force in the rotational direction, so that leakage flux is lessened and the first movable member 6 can be efficiently moved in the rotational direction with great force.

[0044]

Meanwhile, here, a case in which the first movable member 6 undergoes the force oriented in the axial direction and the force oriented in the rotational direction has been described. However, this embodiment is not limited to this case. Since the force oriented in the axial direction and the force oriented in the rotational direction are applied to the first movable member 6 through the spring member 8, an arrangement may be employed in which the second movable member 7 undergoes the forces by switching magnetic structures of the second movable member 7 and the first movable member 6.

[0045]

(Second embodiment)

Hereinafter, a second embodiment of the present invention directed to Claims 1, 2 and 4 to 6 is described with reference to Fig. 10. The second embodiment is different from the first embodiment in shapes and relative position of the first stationary member 2 and the second stationary member 4. Other constructions of the second embodiment are the same as those of the first embodiment.

[0046]

As viewed in the axial direction, the magnetic pole portions of the first stationary member 2 and the second stationary member 4 are spaced a

predetermined gap from a magnetic pole face formed by a cylindrical side face of the first movable member 6. The magnetic pole portions of the second stationary member 4 are provided in the recesses of the E-shaped first stationary member 2, respectively. Therefore, as viewed in the axial direction, end portions of the magnetic pole portions of the first stationary member 2 and end portions of the magnetic pole portions of the second stationary member 4 form an overlap portion CP overlapping in three dimensions. Thus, a gap G is formed between the magnetic pole portions of the first stationary member 2.

[0047]

By the above described arrangement, since the first stationary member 2 and the second stationary member 4 secure a space for increasing an area in which the first stationary member 2 and the second stationary member 4 confront the first movable member 6, the area can be increased, so that a large force can be applied to the first movable member 6. Meanwhile, by providing the gap G, magnetic reluctance of a magnetic path WC which does not contribute to application of a force to the first movable member 6 and proceeds in, for example, the axial direction in the order of an N-pole of the first stationary member 2, the gap G, the second stationary member 4, the gap G and an S-pole of the first stationary member 2 is increased so as to reduce magnetic flux flowing through the magnetic path WC, so that a large force can be applied to the first movable member 6. Here, a width of the gap G is designed in view of a width of a gap between the first movable member 6 and the stationary members, etc.

[0048]

In the second embodiment, since the first stationary member 2 and the second stationary member 4 secure the space containing the area for

confronting their magnetic pole portions with the first movable member 6 as described above, the area for confronting their magnetic pole portions with the first movable member 6 can be increased. Thus, since magnetic reluctance of the magnetic path between the first stationary member 2 and the second stationary member 4 increases, the magnetic flux which does not contribute to application of the force to the first movable member 6 can be reduced. Therefore, a large force can be applied to the first movable member 6 in the axial direction and in the rotational direction.

[0049]

(Third embodiment)

Hereinafter, a third embodiment of the present invention directed to Claims 1, 2 and 4 to 7 is described with reference to Fig. 11. The third embodiment is different from the first embodiment in shape of the first movable member 6 and relative position of the first movable member 6 and the first stationary member 2. Other constructions of the third embodiment are the same as those of the first embodiment.

[0050]

The first movable member 6 includes the cylindrical magnets having a thickness smaller than an axial width of the recesses of the E-shaped first stationary member 2 and a diameter of the cylindrical magnets is formed larger than a distance between the corresponding magnetic pole portions of a pair of the first stationary members 2 such that the cylindrical magnets are provided in between the E-shaped magnetic pole portions of the first stationary member 2. Hence, axial motion of the first movable member 6 is restricted within the recesses of the first stationary member 2. Meanwhile, each of the two magnets 6ba and

6bb has opposite faces orthogonal to the axial direction and the first movable member 6 is rotated such that an end portion of the faces of each of the magnets 6ba and 6bb traverses each of the recesses of the E-shaped first stationary member 2. Thus, since an area in which magnetic pole portions of the magnets 6ba and 6bb of the first movable member 6 confront the magnetic pole portions of the first stationary member can be increased, the first movable member 6 is moved in the axial direction with great force.

[0051]

In the third embodiment, since the area in which the magnetic pole portions of the magnets 6ba and 6bb of the first movable member 6 confront the magnetic pole portions of the first stationary member 2 can be increased as described above, the first movable member 6 can be moved in the axial direction with great force.

[0052]

(Fourth embodiment)

Hereinafter, a fourth embodiment of the present invention directed to Figs. 1, 2 and 4 to 6 is described with reference to Figs. 12 and 13. The fourth embodiment is different from the first embodiment in shape of the first movable member 6. Other constructions of the fourth embodiment are the same as those of the first embodiment.

[0053]

The magnets 6ba and 6bb of the first movable member 6 are formed into a cylindrical shape of an identical size such that not only opposed end faces of the magnets 6ba and 6bb are brought into contact with each other but other end faces of the magnets 6ba and 6bb remote from the opposed end faces

are flush with axial opposite end faces of the first stationary member 2, respectively. The contacting opposed end faces of the magnets 6ba and 6bb are disposed at an axial center of the central magnetic pole portion of the E-shaped first stationary member 2.

[0054]

By the above described arrangement, a position where the other end faces of the magnets 6ba and 6bb are flush with the axial opposite end faces of the first stationary member 2, respectively presents a stable point. At this time, thrust characteristics are indicated in Fig. 13 by a curve FZ2 in which electric current does not flow through the coil, a curve FP2 in which electric current flows through the coil in a plus direction and a curve FM2 in which electric current flows through the coil in a minus direction. Namely, if the first movable member 6 is displaced in the axial direction, the characteristics are such that a force for returning the first movable member 6 in the reverse direction is generated. Therefore, since the first movable member 6 is operated as if the movable member 6 were coupled with a return spring, a spring having a low spring constant can be used as the spring member 8.

[0055]

In the fourth embodiment, the position where the other end faces of the magnets 6ba and 6bb are flush with the axial opposite end faces of the first stationary member 2, respectively presents the stable point as described above. Hence, as axial displacement of the first movable member 6 becomes larger, larger force is applied to the first movable member 6 in the direction opposite to that of the axial displacement, so that effect of the return spring can be gained.

[0056]

Meanwhile, the magnet portion 6b of the first movable member 6 is formed by the two magnets held in contact with each other but the two magnets may be replaced by a single magnet in which magnetization directions are different at two locations.

[0057]

(Fifth embodiment)

Hereinafter, a fifth embodiment of the present invention directed to Claims 1, 2 and 4 to 6 is described with reference to Fig. 14. The fifth embodiment is different from the first embodiment in method of winding the first coil 3 around the first stationary member 2. Other constructions of the fifth embodiment are the same as those of the first embodiment.

[0058]

In contrast with the first embodiment in which the first coil 3 wound around the central magnetic pole portion of the E-shaped first stationary member 2 as shown in Fig. 14(a), the first coil 3 is dividedly wound around each of the opposite magnetic pole portions of the first stationary member 2. At this time, these coils 3 are connected to each other such that the central magnetic pole portion and the opposite magnetic pole portions are excited to different magnetic poles, respectively. By winding the first coils 3 around the first stationary member 2 dividedly, effect of thickness of the wound first coil 3 is less than that of winding the first coil 3 around the single location, so that a space for winding the first coil 3 around the first stationary member 2 can be reduced. Meanwhile, as shown in Fig. 14(c), the first coil 3 can also be wound around each of the magnetic pole portions of the first stationary member 2 dividedly.

[0059]

In the fifth embodiment, since by winding the first coil 3 around the first stationary member 2 dividedly, effect of thickness of the wound first coil 3 is less than that of winding the first coil 3 around the single location as described above, the space for winding the first coil 3 around the first stationary member 2 can be reduced further.

[0060]

(Sixth embodiment)

Hereinafter, a sixth embodiment of the present invention directed to Claims 1, 3 and 4 to 6 is described with reference to Fig. 15. This sixth embodiment is different from the fourth embodiment in that the first movable member 6 does not undergo force from the second stationary member 4 but the second movable member 7 undergoes force from the second stationary member 4. Other constructions of the sixth embodiment are the same as those of the fourth embodiment.

[0061]

The second movable member 7 includes two magnets 7a and 7b held in contact with each other in the same manner as the first movable member 6 and a circular through-hole having a diameter larger than that of the shaft 6a is formed at a central axis of each of the magnets 7a and 7b. The magnets 7a and 7b are accommodated in the housing portion 1a so as to be arranged between the first movable member 6 and the casing 1 in the axial direction such that the shaft 6a is inserted through the through-hole via a bearing. The magnets 7a and 7b are supported between the first movable member 6 and the casing 1 by using the spring member 8. A mass of the second movable member 7 is set close to that of the first movable member 6. The second stationary member 4 has a shape

identical with that of the fourth embodiment and confronts the second movable member 7.

[0062]

By the above described arrangement, since a magnetic flux which contributes to the force oriented in the axial direction and a magnetic flux which contributes to the force oriented in the rotational direction can be handled separately, design of the spring resonant system is facilitated.

[0063]

In the sixth embodiment, since the force oriented in the axial direction is applied to the first movable member 6 and the force oriented in the rotational direction is applied to the second movable member 7, a magnetic path for generating the force oriented in the axial direction and a magnetic path for generating the force oriented in the rotational direction are separated from each other, so that design of a magnetic circuit is facilitated .

[0064]

Meanwhile, here, an arrangement in which the force oriented in the axial direction is applied to the first movable member 6 and the force oriented in the rotational direction is applied to the second movable member 7 has been described but may be replaced by a reverse arrangement.

[0065]

Meanwhile, only an arrangement in which each of the magnets of the driving force generator 6b of the first movable member 6 is symmetrical with respect to the rotational axis, a pair of the first stationary members 2 symmetrical with respect to the rotational axis are excited in an antiphase state and a pair of the second stationary members 4 symmetrical with respect to the rotational axis

are excited in an antiphase state has been described. However, this arrangement may be replaced by another arrangement in which the single first stationary member 2 and the single second stationary member 4 are provided such that only a magnetic pole at one side of the magnet is used.

[0066]

Furthermore, an arrangement in which the driving force generator 6b includes the two magnets has been described but a single magnet may also be used instead. In this case, when the first stationary member 2 has one magnetic portion or two magnetic portions (for example, two C-shaped magnetic portions) in the axial direction and the second stationary member 4 has one magnetic portion, the first movable member 6 can be moved in the axial direction and in the rotational direction.

[0067]

Meanwhile, the mass of the first stationary member 6 is set close to that of the second stationary member 7. However, the masses of the first and second stationary members 2 and 4 may also be adjusted unequally to each other, so that effects are gained that vibrations in the axial direction can be lessened and amplitude can be adjusted.

[0068]

[Effects of the Invention]

In the invention of Claim 1, since a spring resonant system is formed by the first movable member, the second movable member, the casing and the spring member provided among these members and deflectable in the axial direction, while resonant operation of the first movable member or the second movable member is performed in the axial direction by imparting to the first

movable member or the second movable member the force oriented in the axial direction upon excitation of the magnetic path passing through the first stationary member by the first coil and motion of the first movable member or the second movable member is performed in the rotational direction by imparting to the first movable member or the second movable member the force oriented in the rotational direction upon excitation of the magnetic path passing through the second stationary member by the second coil, the first movable member can be controlled independently in the axial direction and in the rotational direction.

Meanwhile, since the resonant operation of the first and second movable members can be, respectively, performed oppositely in the axial direction, vibrations caused by inertia force in the axial direction can be reduced.

As a result, since vibrations caused by inertia force can be reduced, it is possible to upgrade degree of freedom of operational control of the actuator which is capable of moving in two directions of the axial direction and the rotational direction.

[0069]

In the invention of Claim 2, since the other of the first and second movable members does not undergo the force from the stationary member, design of the spring resonant system is facilitated in addition of the effect of Claim 1.

[0070]

In the invention of Claim 3, since the magnetic path for generating the force oriented in the axial direction and the magnetic path for generating the force oriented in the rotational direction are separated from each other, design of a magnetic circuit can be facilitated in addition to the effect of Claim 1.

[0071]

In the invention of Claim 4, since the first and second stationary members imparts, by using opposite magnetic poles of the magnet, to the one of the first and second movable members the force oriented in the axial direction and the force oriented in the rotational direction, the spring resonant system can be moved with great force in addition to the effects of Claim 2 or 3.

[0072]

In the invention of Claim 5, since the two magnets of the one of the first and second movable members are positioned so as to confront the first stationary members such that magnetic pole portions of the magnets are disposed at positions suitable for producing the force oriented in the axial direction, leakage flux is lessened and the spring resonant system can be efficiently moved in the axial direction with great force in addition to the effects of Claim 4.

[0073]

In the invention of Claim 6, since the two magnets of the one of the first and second movable members are positioned so as to confront the two magnetic pole portions of the second stationary member such that the magnetic pole portions of the second stationary member are disposed at positions suitable for producing the force oriented in the rotational direction, leakage flux is lessened and the first movable member can be efficiently moved in the rotational direction with great force in addition to the effects of Claim 5.

[0074]

In the invention of Claim 7, since an area for confronting magnetic pole portions of the magnets with the magnetic pole portions of the first stationary member can be increased, the spring resonant system can be moved in the axial

direction with great force in addition to the effects of Claim 5 or 6.

BRIEF DESCRIPTION OF THE DRAWINGS:

Fig. 1 is a partly sectional perspective view illustrating a first embodiment.

Fig. 2 is a sectional view taken along the line A-A in Fig. 1.

Fig. 3 is a sectional view taken along the line B-B in Fig. 1.

Fig. 4 is a sectional view illustrating the first embodiment and includes Fig. 4(a) of its section C-C and Fig. 4(b) of its section D-D.

Fig. 5 is a characteristic diagram of the first embodiment and includes Fig. 5(a) of characteristics between axial displacement and thrust and Fig. 5(b) of characteristics between rotational angle and torque.

Fig. 6 is a sectional view taken along the line B-B, in which a second stationary member of the first embodiment is replaced by an E-shaped one.

Fig. 7 is a sectional view of the E-shaped second stationary member and includes Fig. 7(a) of its section E-E and Fig. 7(b) of its section F-F.

Fig. 8 is a waveform diagram showing operation of the first embodiment.

Fig. 9 is a waveform diagram showing another operation of the first embodiment.

Fig. 10 shows a main portion of a second embodiment and includes Fig. 10(a) of its perspective view and Fig. 10(b) of its top plan view.

Fig. 11 is a sectional view illustrating a third embodiment and corresponding to the section A-A in Fig. 1.

Fig. 12 is a sectional view illustrating a fourth embodiment and corresponding to the section A-A in Fig. 1.

Fig. 13 is a characteristic diagram showing characteristics between axial displacement and thrust in the fourth embodiment.

Fig. 14 is a fragmentary sectional view showing a first stationary member and a first coil in a fifth embodiment.

Fig. 15 is a sectional view illustrating a sixth embodiment and corresponding to the section A-A in Fig. 1.

[Reference numerals]

1: Casing

1a: Housing portion

1b: Bearing portion

2: First stationary member

3: First coil

4: Second stationary member

5: Second coil

6: First movable member

6a: Shaft

6b: Driving force generator

6ba: Magnet

6bb: Magnet

7: Second movable member

7a: Magnet

7b: Magnet

8: Spring member

8a: First spring

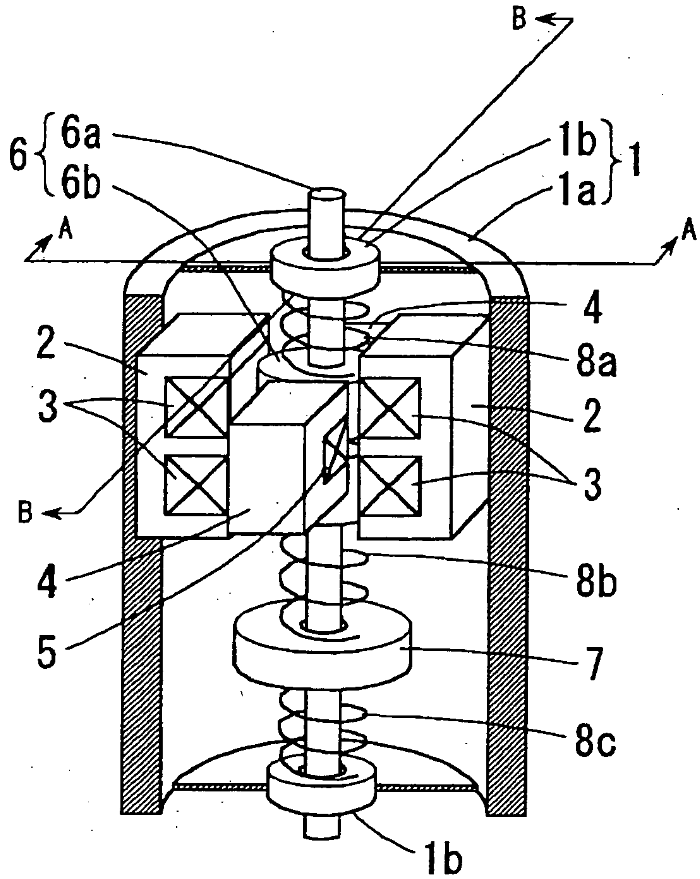
8b: Second spring

8c: Third spring

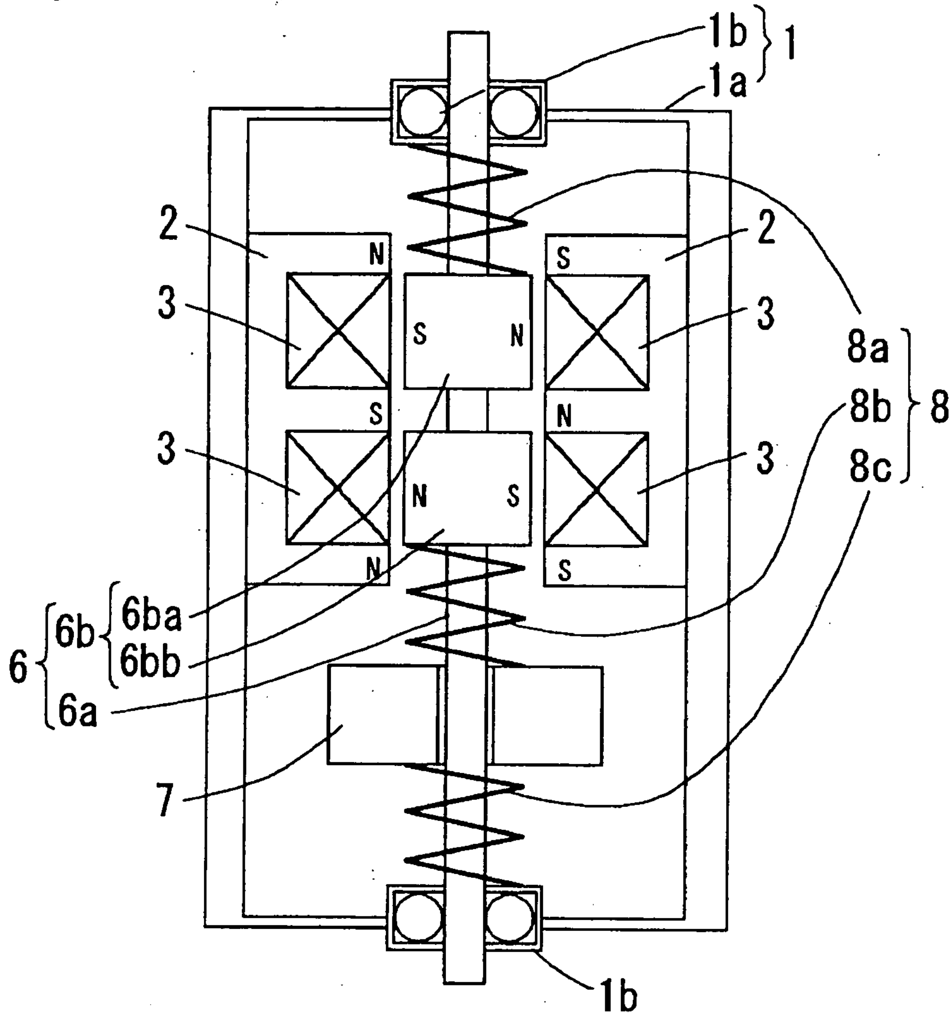
G: Gap

【書類名】　図面　Document name: Drawings

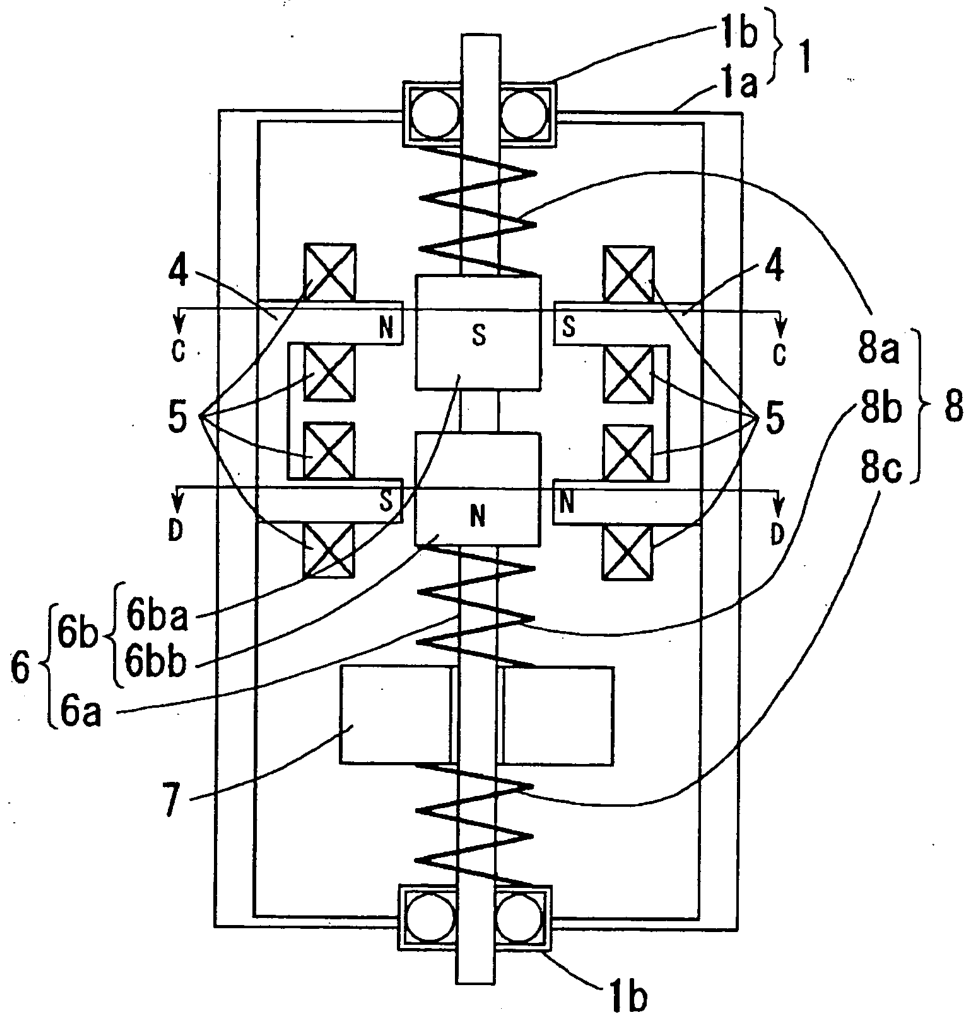
【図１】
Fig. 1



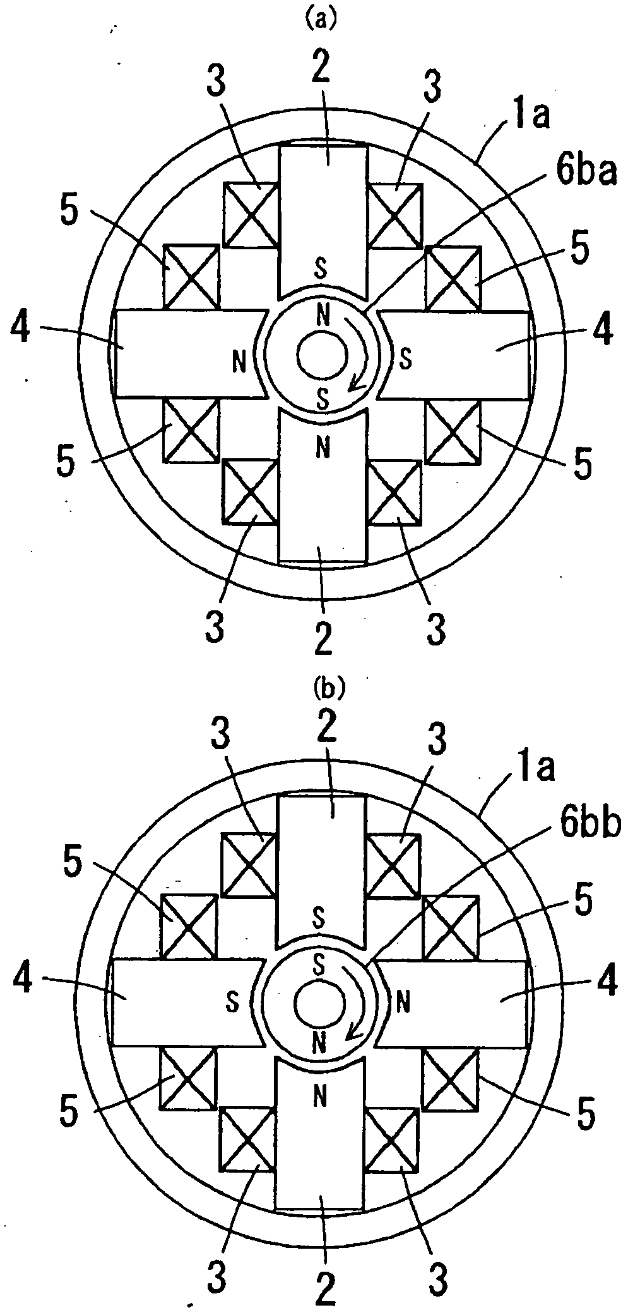
【図２】
Fig. 2



【図３】
Fig. 3

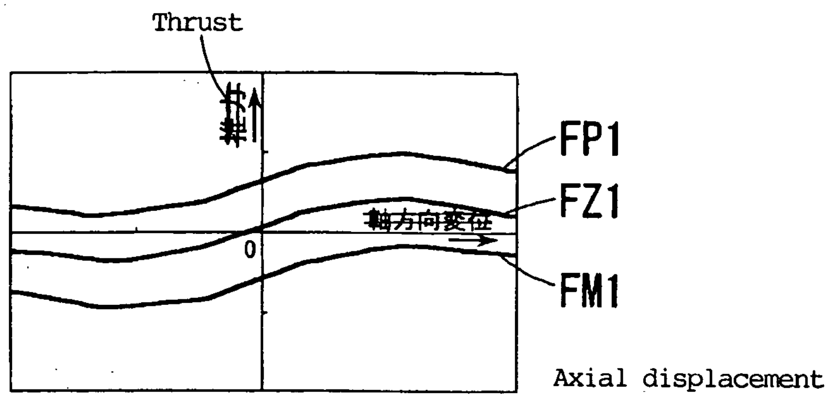


【図４】
Fig. 4

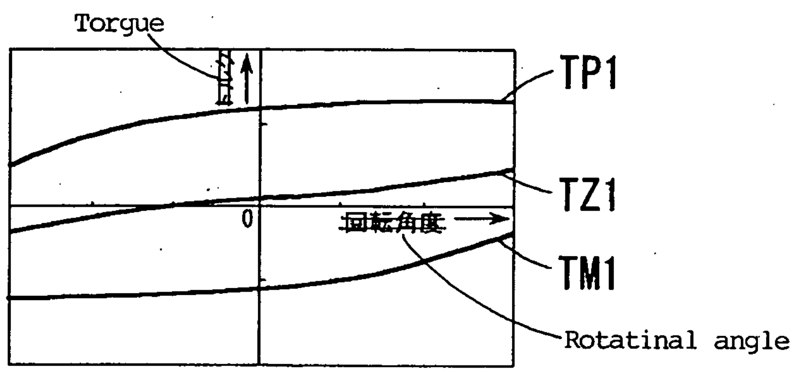


【図５】
Fig. 5

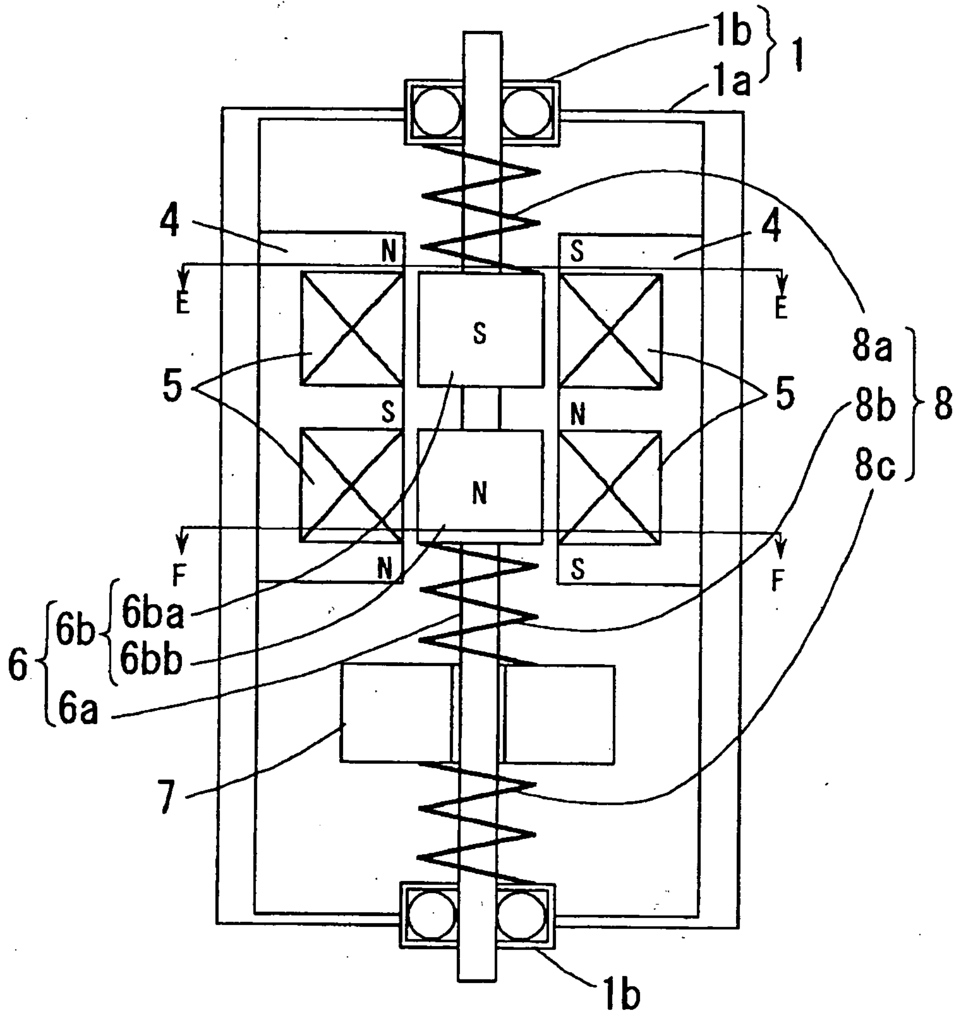
(a)


Thrust
推力
FP1
FZ1
軸方向変位
0
FM1
Axial displacement

(b)

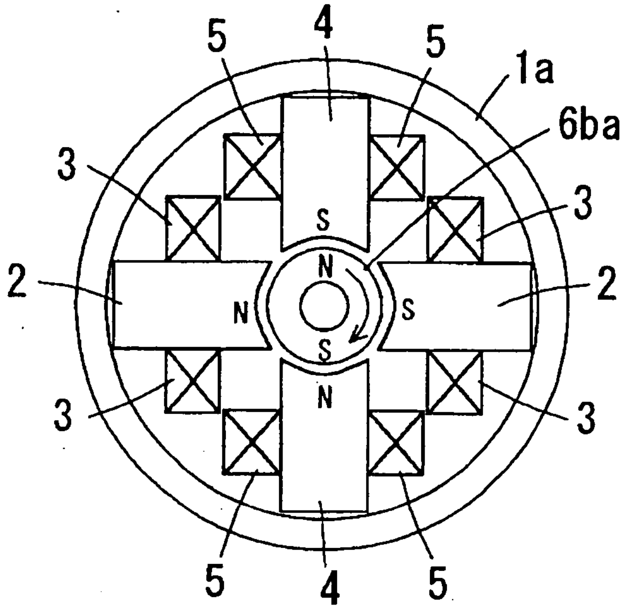

Torgue
トルク
TP1
TZ1
0
回転角度
TM1
Rotatinal angle

【図６】
Fig. 6

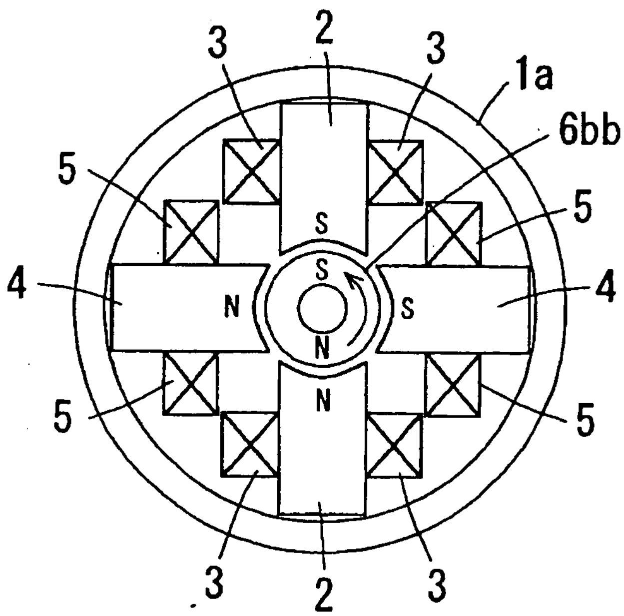


【図７】
Fig. 7

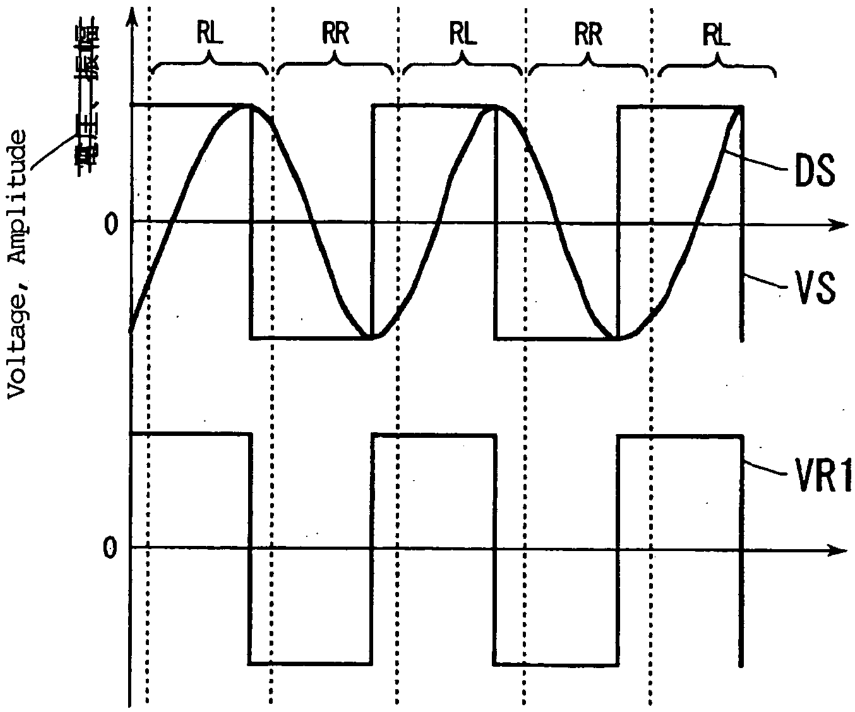
(a)



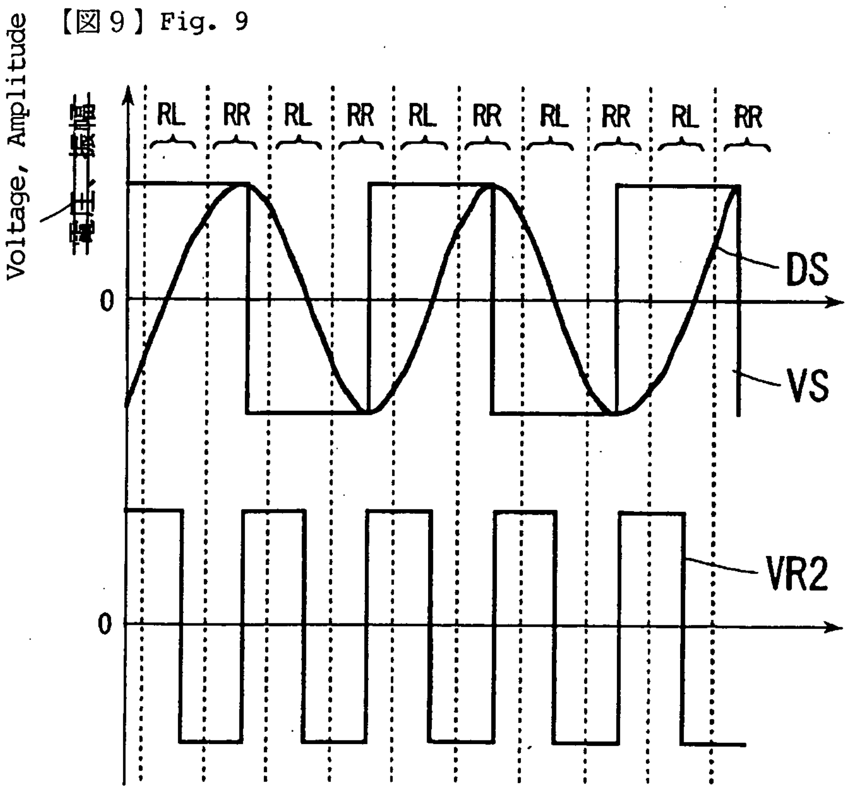
(b)



【図８】
Fig. 8

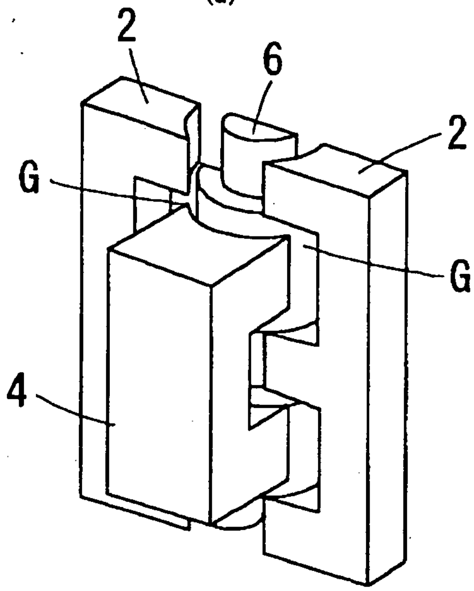


【図９】Fig. 9

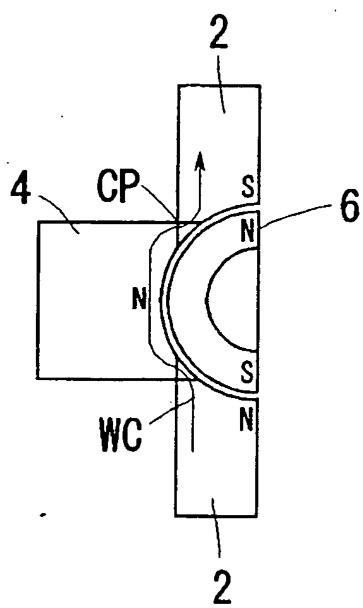


【図１０】
Fig. 10

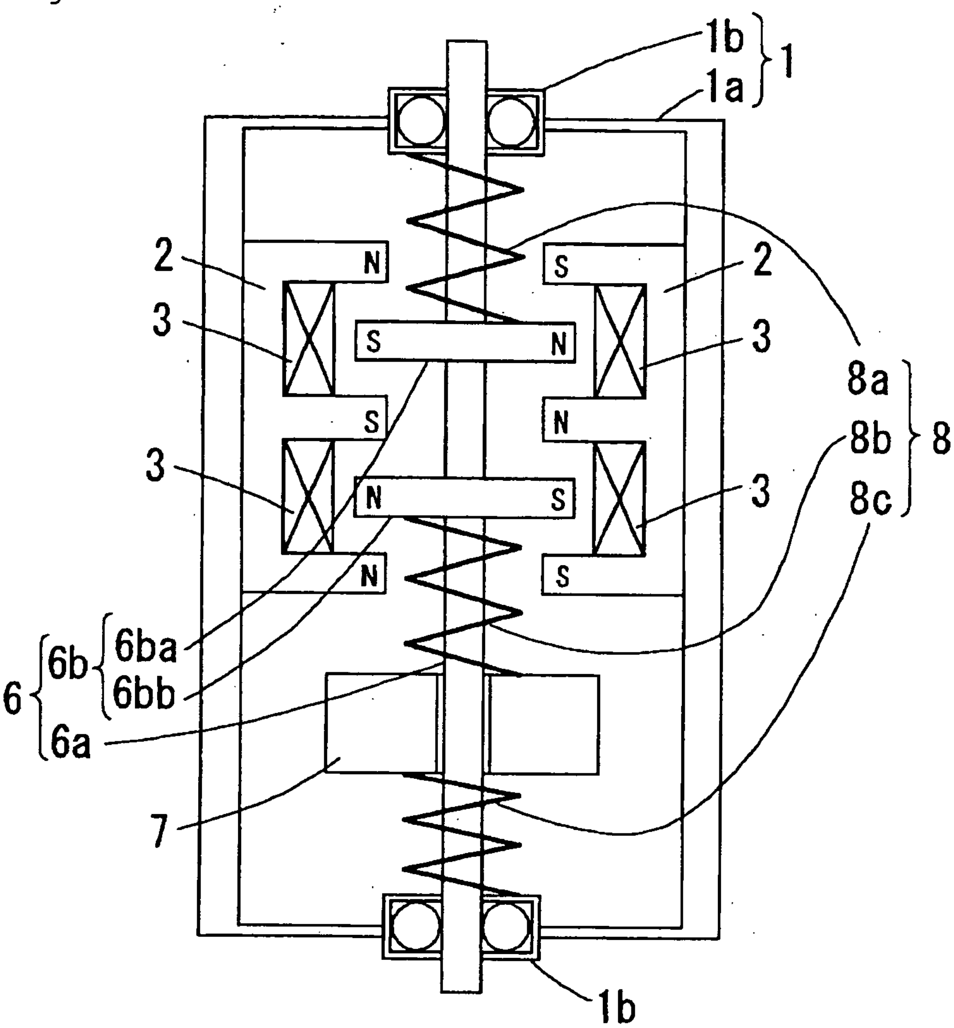
(a)



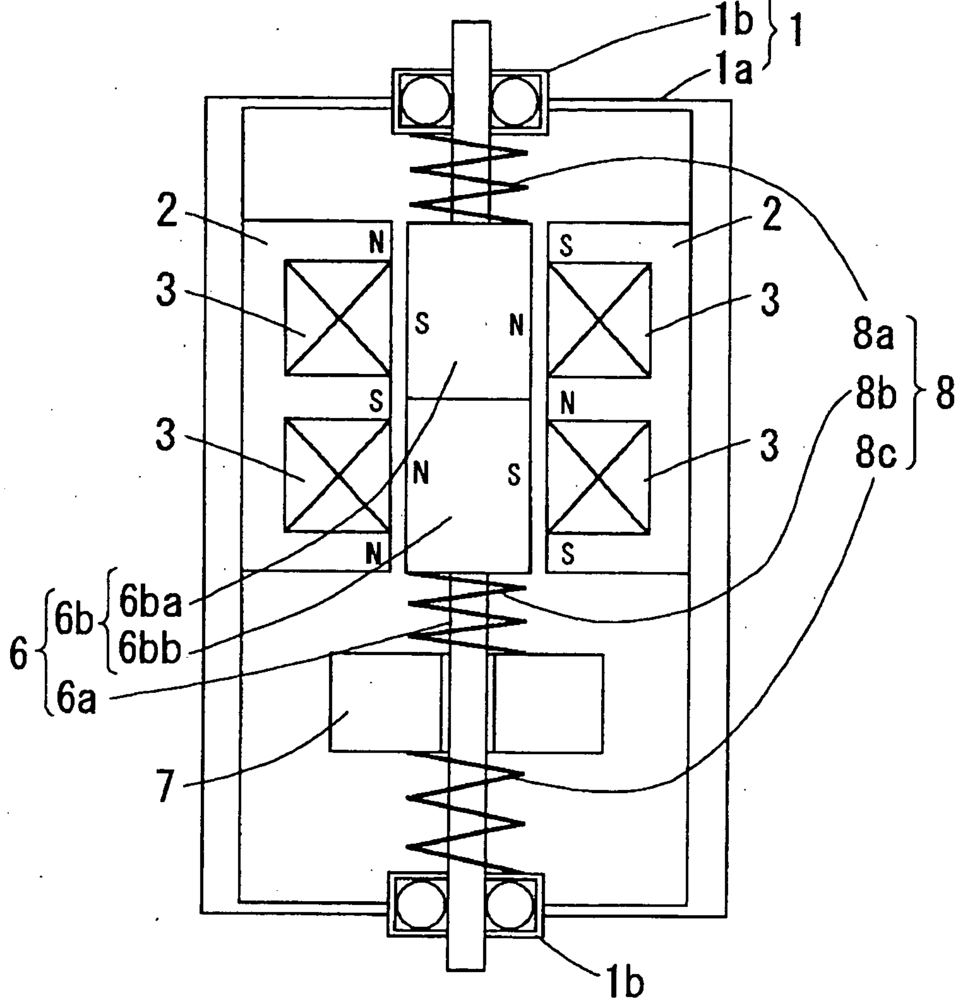
(b)



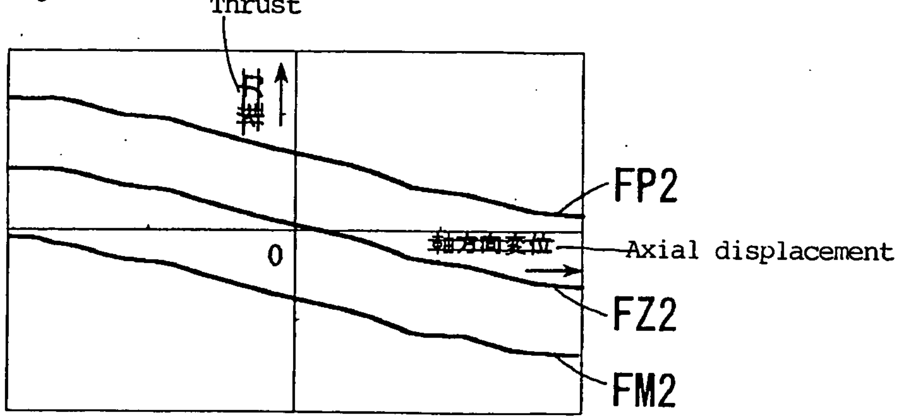
【図１１】
Fig. 11



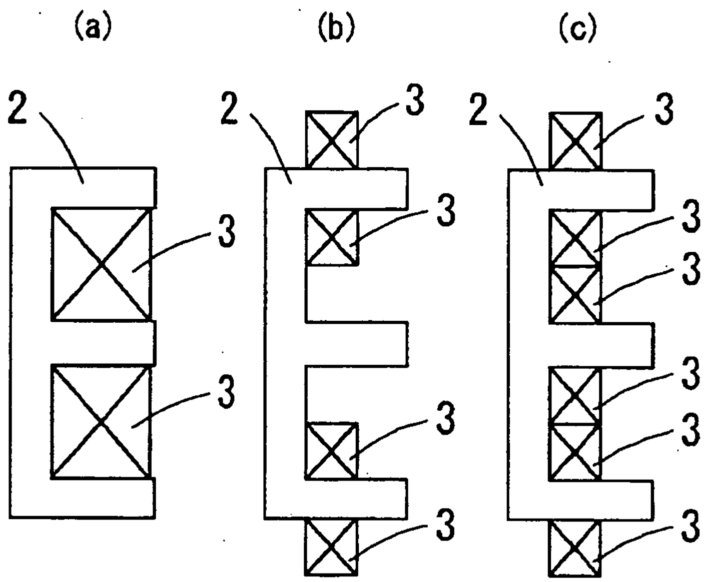
【図１２】
Fig. 12



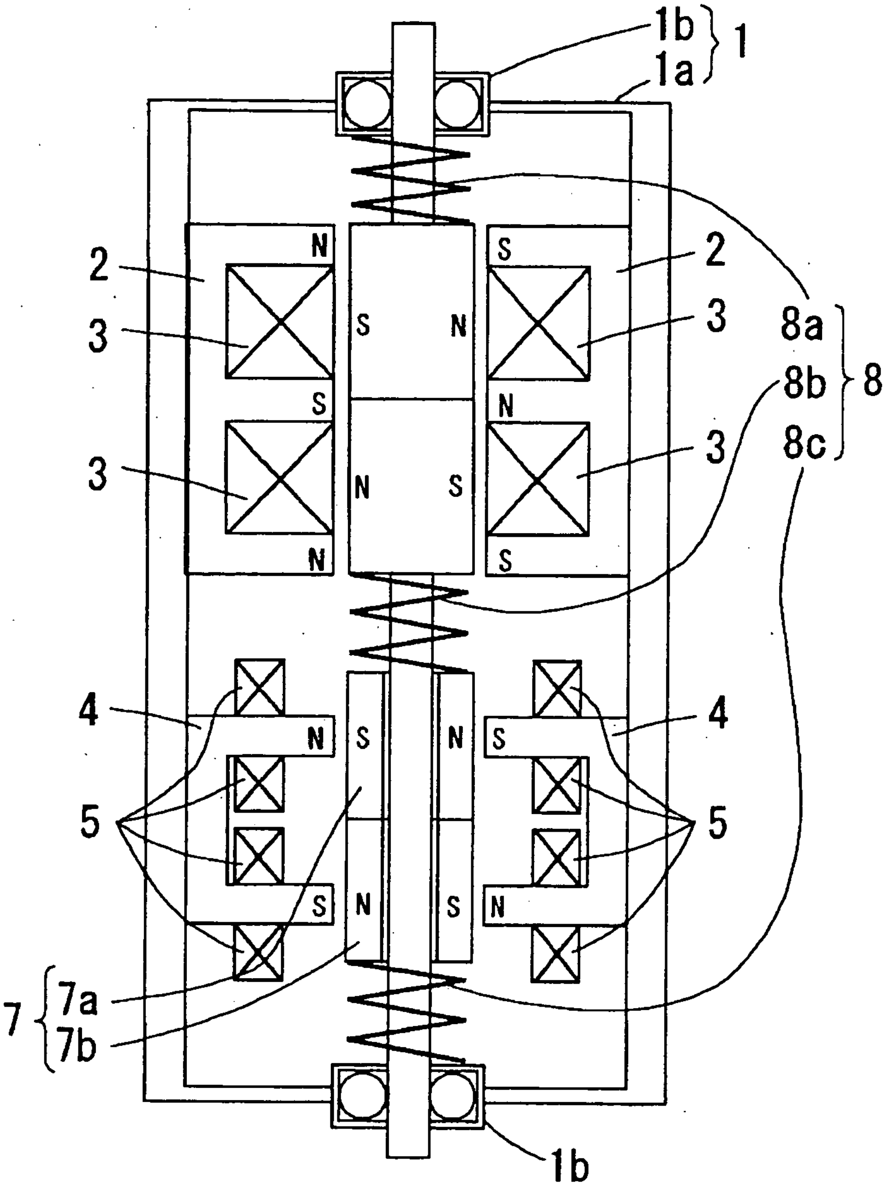
【図１３】
Fig. 13



【図１４】
Fig. 14



【図１５】
Fig. 15



Document Name: Abstract

Abstract:

[Object]

In an actuator which is capable of moving in two directions of an axial direction and a rotational direction, degree of freedom of operational control is upgraded by lessening vibrations caused by inertia force in the axial direction.

[Solution Means]

An actuator of the present invention includes a stationary member which has a coil, a casing which contains the stationary member, a first movable member which has a shaft and is supported by the casing so as to be moved in an axial direction of the shaft and in a rotational direction having the shaft as its rotational axis, a second movable member which is arranged in the axial direction with the first movable member so as to be moved in the axial direction separately from the first movable member and a spring member which is deflected among the casing, the first movable member and the second movable member in the axial direction. Electric current is caused to flow through the coil so as to move the first movable member in the axial direction and in the rotational direction. The stationary member includes a first stationary member for imparting to the first movable member or the second movable member a force oriented in the axial direction and a second stationary member for imparting to the first movable member or the second movable member a force oriented in the rotational direction. The coil includes a first coil for exciting a magnetic path passing through the first stationary member and a second coil for exciting a magnetic path passing through the second stationary member.

[Selected Drawing]

Fig. 1

Applicant Record

Identification No.: 000005832

1. Date of Registration: August 30, 1990 (newly recorded)

   Address: 1048, Oaza-Kadoma, Kadoma-shi, OSAKA

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